Characteristics of α, β^-, and γ Radiation

Objectives: This experiment is designed to give you an appreciation of the range (penetrating capability) of various radiations, the β^- detection efficiency of gas-filled detectors as a function of parameters such as counting geometry and β^- energy, and various factors, such as scattering of radiation, that may have to be allowed for in a typical tracer experiment.

References: Ehmann & Vance: pp. 147-173.

PROCEDURE

A. Alpha Particle Range

Using an ^{241}Am source and a G-M counter, monitor the activity as a function of source-to-detector distance and plot these data (count rate, corrected for geometry as described in Appendix A, vs. total absorber thickness, in mg/cm^2). Assuming the density of air is 1.2 mg/cm^3, calculate the air absorption in mg/cm^2. Add the detector window thickness (see instructor for this information) in mg/cm^2 to obtain the total absorber thickness. Compute the range (in mg/cm^2) as that distance which gives a 50% reduction in activity. Convert this to a range (in cm) in air. Using the relationship between alpha-particle range in air, R (in cm), and alpha-particle energy, E (in MeV),

$$R = (0.005E + 0.285)E^{3/2} \qquad \text{(II.1)}$$

calculate an appropriate range for these ^{241}Am alpha particles and compare with your experimental results. Make additional measurements using very thin absorbers (such as paper) and compare your results to those above (refer to absorber thicknesses in mg/cm^2).

B. Range-Energy Relationship for Beta Particles

With a G-M counter set at the operating voltage, measure the background counts for 5 minutes to obtain the background counting rate (cpm). Place one of the β^- sources on a lower shelf (but so as to maintain a count rate of several thousand cpm) and count for one minute and record the counts. Make similar measurements for each absorber (placed on the top shelf) in a set of aluminum absorbers until an absorber thickness is reached for which the observed count rate is essentially just the background counting rate (you will have to increase the counting time as absorber thickness increases to obtain good statistics). Including detector window thickness, air absorption and sample window thickness, plot log of <u>net</u> count rate vs. total absorber thickness (in mg/cm^2), and extrapolate your data to an absorber thickness at 10 net cpm. Do the same for 3 other beta sources of varying energy. Using the given E^{max} values for the four radionuclides, plot log (E^{max}) vs. log of extrapolated absorber thickness (mg/cm^2) to obtain a β^- range-energy relationship curve. For each beta source, calculate a range using the Glendenin equations (see Ehmann & Vance, p. 156) and compare these to your measured values.

C. Beta Counting Efficiency

Using the available calibrated β^- sources, measure the activity of each source on the top shelf of your detector support. Correct all values for background and coincidence losses (if necessary). Calculate the counting efficiency ε using the relationship

$$\varepsilon = \frac{R}{A} \qquad \text{(II.2)}$$

where R is the observed, corrected count rate and A is the emission rate of the source (this will have to include a correction for the transmission factor [see instructor], and some values of A may have to be corrected for decay). Plot your data as counting efficiency vs. maximum beta energy.

In a similar fashion, count the calibrated β^- sources with the proportional counter and calculate the counting efficiency for each. Compare these results with those for the G-M counter.

D. Gamma Counting Efficiency

Using one high-energy and one low-energy gamma-ray standard source, determine the gamma counting efficiency on one of the shelves of your detector support. Compare these efficiencies to those for beta counting.

E. Gamma-Ray Attenuation

With the narrow beam geometry system set up for you, measure the effectiveness of various materials to attenuate the gamma rays emitted by a ^{137}Cs source. The instructor will have positioned the ^{137}Cs source for you in this experiment. This source is quite radioactive and appropriate precautions should be taken to avoid direct exposure to the radiation beam. Dosimeters should be worn at all times. Gamma-ray attenuation can be expressed as

$$I = I_0 e^{-\mu x} \qquad \text{(II.3)}$$

where I_0 is the intensity of the incident beam of photons, I is the intensity after traversing a distance x through the absorber, and μ is the <u>linear</u> absorption coefficient (cm^{-1}). Measure the decrease in beam intensity as a function of absorber thickness for different absorber materials (Pb, Al, H_2O) and plot ln I vs. x to get μ. For each absorber calculate a half-thickness value $x_{½}$, which is defined as the thickness of absorber necessary to decrease the initial beam intensity by 50%, from the relationship

$$x_{1/2} = \frac{\ln 2}{\mu} \qquad \text{(II.4)}$$

Calculate the <u>mass</u> absorption coefficient Σ for each absorber material from the relationship

$$\Sigma = \frac{\mu}{\rho} \qquad \text{(II.5)}$$

where ρ is the density of the absorber; Σ has the units cm^2/g. Compare Σ values.

F. Backscattering of Beta Radiation

One factor that affects the counting of β^- sources is the scattering of beta radiation from the source mounting and counting chamber. The most important considerations for reflection, or backscattering, from the source mount are thickness and atomic number of the mounting material and the energy of the radiation. For a given backing material, an increase (build-up) in the count rate is observed as the backing thickness increases up to a certain point, then no further increase in counting rate is seen for increases in backing thickness. This 'saturation' value of the backing thickness is called the infinite thickness for that radiation, and is approximately independent of the atomic number of the backing material, if expressed in mg/cm^2. However, the magnitude of the build-up is quite dependent upon the atomic number of the backing material.

Using the ^{32}P sources prepared for this experiment, mount the source (as shown by your instructor) on a shelf tray and measure the counting rate of the source with only the thin plastic film as backing. This count rate will be taken as R_0, the counting rate for the ^{32}P source with no added backing. Allow time for the collection of 30,000 or more counts.

Measure the counting rate for various thicknesses of aluminum backing. Plot the build-up curve for aluminum and show where the saturation thickness is effectively reached. Measure the counting rate for saturation thicknesses of the various backing materials available and calculate the backscattering factor f_B according to

$$f_B = \frac{R_{sat.\ backing}}{R_0} \qquad \text{(II.6)}$$

for each saturation backing. Plot f_B vs. the atomic number of the backing material.

G. Cloud Chamber

A modern cloud chamber consists of a closed container filled with a supersaturated vapor, for example, methanol in air. When ionizing radiation passes through the vapor it leaves a trail of ions that serve as points for the vapor to condense on. The path of the radiation is thus indicated by a track of tiny liquid droplets in the supersaturated vapor.

A simple cloud chamber design uses an alcohol-soaked strip around the top of a glass chamber. A large temperature difference is maintained between the chamber top and bottom by setting the chamber on dry ice. The air-methanol vapor mixture cools as it diffuses toward the chamber bottom, becoming supersaturated. If a radiation source is placed on the bottom of the chamber, its emissions (alpha particles or beta particles) will produce distinctive tracks that can be readily seen with the aid of a flashlight (see figure below).

Place alpha and beta radiation sources in the cloud chamber and take note of the specific characteristics of the tracks produced by the different forms of ionizing radiation emitted. Account for the differences observed.

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